NATIONAL BUREAU OF STANDARDS REPORT

6417

A MONTE CARLO PROCEDURE FOR CW CASUALTY RATE ASSESSMENT

by
A. J. Goldman and J. M. Cameron

Final Report (30 April 1959)
to
U. S. Army Chemical Warfare Laboratories
Army Chemical Center, Maryland
on Contract No. CMLMC-PA-2A 9-405-5779

U. S. DEPARTMENT OF COMMERCE
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NBS PROJECT	NBS REPORT
1102-40-5222	6417

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FOREWORD

This report presents a method of machine computation of the casualty rates from CW munitions using a Monte Carlo method. A discussion of the degree of flexibility required of such machine programs and of the computing times involved for calculations using the model developed by the University of Pennsylvania CARAMU group is given.

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Chief, Applied Mathematics
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A MONTE CARLO PROCEDURE FOR CW CASUALTY RATE ASSESSMENT

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A highly flexible Monte Carlo procedure for CW casualty rate assessment has been devised. Individual doses, intake functions and munition arrivals can either be taken from empirical data or generated within the computer itself. Capability for random variation of many of the parameters has been incorporated. Estimates of computation time indicate that the simulations should be performed on a fast computer such as the UNIVAC 1103 or IBM 704.

The following rough estimates are for the IBM 704, but should not be greatly different for the UNIVAC 1103. Programming time is estimated at 3 man-months from the time all pertinent information has been furnished the programmers; programming expense is estimated at $4,000. Assuming situations involving 100 munitions, computation time would be about 6-10 minutes per simulation if 2,000 grid-points and 250 time-moments are employed, and about 1 minute per simulation if 500 grid-points and 100 time-moments are employed. There are also initial computations of individual doses, done only once for each set of simulations, requiring about 6 minutes in the first case and 2 minutes in the second.

1. Introduction

The general class of CW situations to be studied can be described as follows. A number of CW munitions arrive in an area at random points and random times. The toxic agent from these munitions flows downwind. The casualty rate among the personnel in the area can be determined in terms of

(i) the equation describing the flow of agent from each munition,

(ii) the arrival points and arrival times of the munitions,

(iii) the parameters expressing meteorological conditions,

(iv) the deployment of personnel in the area, and

(v) the equations describing the breathing and masking behavior of this personnel.

Since items (ii) - (v) should ideally be regarded as (entirely or partly) probabilistic, the possibility of evaluating casualty rates by a "Monte Carlo" simulation suggested itself. Within a definite set of CW situations, such a simulation process involves the calculation of the number of casualties for each of a number of specific CW situations chosen at random within the set. If the specific situations are properly chosen, they can be considered a statistical sample from which conclusions can be drawn about

the "average" behavior of situations from the set. Since the computations for each specific CW situation are quite onerous, and since a great many such simulations must be considered to ensure the statistical significance of the results (i.e., a sufficiently large sample must be taken), the work would require use of an electronic computer. The National Bureau of Standards was therefore asked to make a study with the following objective:

"To determine the most efficient means of conducting Monte Carlo studies of CW casualty problems on high speed computers."

This study is the subject of the present report. The investigation takes as its starting point the mathematical model developed by the University of Pennsylvania(1), and has benefitted from our access(2) to related work done by the Operations Research Office of John Hopkins University. As requested by the sponsor, particular emphasis was placed on making the Monte Carlo method flexible enough

(a) to facilitate use of empirical data when desired, and

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(1) Contract No. DA 18-108-Cml-5956. See Bimonthly Reports 4-12 and 14, "Casualty Rate Assessment, Project Caramu" (CONF.)

(2) Letter from M. D. Shavit to J. M. Cameron dated 9 Feb. 1959.

(b) to permit convenient study of the effects of changes in the parameters and random distributions involved.

The results of the study are as follows:

(1) A highly flexible way of arranging the simulations has been worked out. It is based upon the natural idea of separating out, so far as is possible, the following factors:

(a) Calculation of the concentration due to a single munition, at a given point at a given moment.

(b) Determination of the intake rate of a person at a given point at a given moment.

(c) Determination of the arrival times and arrival points of all munitions.

(d) Combination of (a), (b), (c) to obtain the dose taken in by a person at a given point.

(e) Determination, using (d), of whether or not a person at a given point has received a lethal dose.

(f) Examination of the output of (e) for all personnel, and compilation of the number of casualties.

(2) Although the program permits consideration of items (ii) - (v) listed above as probabilistic, it is not clear that randomization of items (iii) - (v) would be worth the trouble and computation time required. The structure chosen for the simulation process should facilitate sequential

decision-making on this question during the early use of the program.

(3) It is recommended that the calculations be performed on a fairly rapid computer, such as the UNIVAC 1103 or the IBM 704. The Army Chemical Center's Datatron is roughly 1/35 as fast as the IBM 704[3] (which costs $200-$300/hour), and thus would be financially competitive only if the average cost of Datatron time were less than $10/hour, which seems unrealistically low. The attractive compromise, of doing the heavy calculations on a fast machine and using the results as inputs to a Datatron program for the less onerous portions, seems ruled out without further exploration by the difficulty of adapting IBM or UNIVAC output for use as Datatron input.

(4) A rough estimate of the programming expense required is $4,000. Programming time should be of the order of 3 man-months from the time all pertinent information has been furnished the programmer. Crude estimation methods for computation time are developed in the body of the report. These estimates are for the IBM 704 (the computer with which we are most familiar), but would not be greatly different for the UNIVAC 1103.

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(3) BRL Report No. 1010 (June, 1957), pp. 69-71, 165-166.

(5) Assuming situations involving 100 munitions, rough typical estimates of computation time are 6-10 minutes/simulation if 2000 grid-points and 250 time-moments are employed, and 1 minute/simulation if 500 grid-points and 100 time-moments are employed. There are also initial computations (of individual concentration tables) requiring about 6 minutes in the first case and 2 minutes in the second case.

2. Skeleton of the Program

The accompanying block diagram (Figure 1) gives the skeleton of the program; the details of its anatomy will be described in the subsequent sections of the report, in which each block is broken down into sub-blocks. It is important to note that empirical data can be inserted at any of the points indicated in Figure 1; such data would render unnecessary (except for possible "data-processing") the calculation of whichever of BLOCKS 1, 2, 3 are involved. The "optional prints" are all on magnetic tape; the first one, for example, gives a set of individual concentration outputs which can be used later with a variety of intake functions.

This seems the best place to describe an important (and natural) feature of our approach, namely the discretization of space and time. We replace the region in which the personnel are located by a finite set of (x,y) - points (with $x > 0$), sprinkled sufficiently densely as to "represent" the region adequately. The x - coordinates of these points must be uniformly spaced, and the same must hold for their y - coordinates. (The spacing need not be the same for both.) All personnel are located at these points, and each munition arrival occurs at one of these points. Analogously, we replace the true "continuous" time scale

by a discrete finite set of uniformly spaced t-moments; dosages are evaluated only at these moments, and each munition arrival occurs at one of these moments.

Let us define

(2.1) $\#(p)$ = number of (x,y) - points used

(2.2) $\#(t)$ = number of t-moments used.

The restriction on $\#(p)$ in the program is

(2.3) $$\#(p) \leq 30{,}000$$

(for the NBS IBM 704); this is far higher than what is needed, and values in the range

(2.4) $$500 \leq \#(p) \leq 2{,}000$$

seem realistic.

There is no restriction on $\#(t)$ in the program, but it is desirable (as will be seen from later sections) that $\#(t)$ be kept reasonably small, to avoid excessive tape inputs and outputs. Heuristic evidence that $\#(t)$ need not be chosen too large is given by the following argument: Total dose (for a person at a given point) is obtained by integrating, over the appropriate time range, the product of the intake function by the sum of the individual dosages due to the various munitions. The integration cannot conveniently be carried out in closed form, and so must be done by "numerical integration", i.e., approximation by a finite sum. The size of $\#(t)$

is significant only because it affects the accuracy of this approximation. Now the various intake functions proposed[4] have piecewise linear graphs, and such functions, while annoying to deal with analytically, tend to give good results in numerical integration without too fine a "mesh size", i.e., for reasonably small values of #(t).[5] We believe that

$$100 \leq \#(t) \leq 250 \tag{2.5}$$

is a realistic estimate.

Incidentally, it is not difficult to check on whether #(p) and #(t) are large enough; one simply repeats a trial problem using (say) 2#(p) and 2#(t) instead, and sees whether or not the final results differ appreciably.

Returning to the block diagram, we point out that arrow ① is to be omitted if the meteorological conditions and munition constants are kept fixed throughout the sample (instead of being varied randomly from simulation to simulation). Keeping these factors fixed seems appropriate on common-sense grounds (i.e., one is interested in studying a specific munition type under specified meteorological

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(4) See the Project Caramu reports, op. cit.
(5) The argument loses some force because the integrand is not the intake function itself, but rather a product with the intake function as one factor.

conditions), and also effects great savings in computation time. Additional savings in computation time (via the elimination of arrow ②) might be achieved if the personnel deployment and the activity, breathing behavior, and masking time for each person (they may vary from person to person) are kept the same for each simulation in the sample; this may turn out to be advisable.

3. Computation of Individual Concentrations (BLOCK 1).

The concentration at time T at a point (X,Y) due to a munition arriving at time τ at the point (ξ,η) is given,[6] in terms of the differences

(3.1) $$x = X-\xi, \quad y = Y-\eta$$

(3.2) $$t = T-\tau,$$

by the modified Sutton equation

$$(3.3) \qquad \chi(x,y,t) = \frac{Q_o\left[1-ae^{-b\left(t-\frac{x}{u}\right)}\right] \exp\left\{\frac{-(x-ut)^2 + y^2}{k(t^{\beta}+\alpha)}\right\}}{\pi^{3/2}\, k \sqrt{k_z}\, (t^{\beta}+\alpha) \sqrt{t^{\beta}+\alpha_z}},$$

where Q_o = source strength at arrival,

a,b = constants used in expressing the decay of source strength ($a=0$ for instantaneous sources),

α,α_z = constants expressing the extent of a volume source ($\alpha=\alpha_z=0$ for a point source),

k,k_z,β = constants associated with diffusion from an instantaneous point source,

u = wind velocity (the positive axis of abscissae points downwind).

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(6) See the Project Caramu reports, op. cit.

The equation is used for $x>0$, $t>0$, and we assume (without further explicit mention) that appropriate instructions in BLOCK 4 effectively define

(3.4) $\chi(s,y;t) = 0$ if $x\leq 0$ or $t\leq 0$.

The function of BLOCK 1 is to compute $\chi(x,y;t)$ for all (x,y)-points and all t-moments. In discussing this computation, we will at first assume that the constants Q_o,a,b, etc. are "given". The major part of computation time (in calculating a single χ-value) is taken up with exponentiation, logarithm-taking, and formation of square roots; since β is not an integer, t^β is computed as $\exp(\beta \log t)$. We list below the maximum computation time for the relevant standard IBM 704 subroutines (thus obtaining conservative estimates):

Operation	Time (in sec.)
Exponential	.0026
Logarithm	.0022
Square Root	.0015

In calculating a single χ-value, we would require three exponentiations for

$$e^{-b(t-\frac{x}{u})}, \quad \exp(\beta \log t), \quad \exp\left\{-\frac{(x-ut)^2+y^2}{k(t^\beta+\alpha)}\right\}$$

one logarithm (the "log t" in t^β), and one[7] square

(7) We assume that $\sqrt{k_z}$, rather than k_z, is "given" at this stage.

root (for $\sqrt{t^{\beta}+\alpha_z}$). Thus the time for computing all the desired χ-values (there are $\#(p)\#(t)$ such values) would apparently be roughly given by

(3.5) $\#(p)\#(t)\ (3(.0026)+.0022+.0015) = .0115\#(p)\#(t)$ seconds.

For the upper limits $\#(p) = 2000$, $\#(t) = 250$ suggested in (2.4) and (2.5), this is about 16 hours computing time; for the lower limits, about $1\frac{1}{2}$ hours.

Fortunately these computation times can be drastically reduced by considering a fixed t-moment and computing $\chi(x,y;t)$ for all (x,y)-points, going on to the next t-moment and doing the same, etc.[8] For a fixed t-moment, each (x,y)-point requires the calculation of the two exponentials

$$e^{bx/u}, \quad \exp\left\{-\frac{(x-ut)^2+y^2}{k(t^{\beta}+\alpha)}\right\};$$

for each t-moment, the calculation of

$$e^{-bt}, \quad t^{\beta} = \exp(\beta \log t), \quad \sqrt{t^{\beta}+\alpha_z}$$

requires two exponentiations, one logarithm-taking, and one square root extraction. Thus (3.5) is replaced by the estimate

$$\#(t)[2.(0026)+.0022+.0015]+ \#(p)\#(t)\ (2)\ (.0026), \text{ or}$$

(3.6) $$\#(t)\ [.0089 + .0052\ \#(p)] \quad \text{seconds},$$

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(8) The form of (5.3) makes it inadvisable to try the reverse order; i.e., to consider a fixed (x,y)-point and compute $\chi(x,y;t)$ for all t-moments, then do the same for another (x,y)-point, etc.

which yields about 45 minutes (instead of 16 hours) for the upper limits in (2.4) and (2.5), and yields about 9 minutes (instead of $1\frac{1}{2}$ hours) for the lower limits.

We can push the same idea one step further to take advantage of the fact that $e^{bx/u}$ does not involve y. Namely, within the calculations for a given t-moment, we consider a fixed x-value and calculate $\chi(x,y;t)$ for all y-values paired with x among our set of points representing the region, then do the same for the next x-value, etc. If we define

(3.7) $\#(x)$ = number of x-values used,

(3.8) $\#_x(y)$ = number of y-values paired with x,

then $\#(p) = \sum_x \#_x(y)$

and the method just described reduces (3.6) to the estimate

(3.9) $\#(t)\ [.0089 + .0026 \sum_x \{ 1+\#_x(y) \}]$. ,

a saving of

(3.10) $.0026\ \#(t)\ [\ \#(p) - \#(x)\ ]$.

We expect to deal usually with <u>rectangular</u> arrays of (x,y)-points, for which

(3.11) $\#_x(y) = \#(y)$ (the same for all x) and

(3.12) $\#(p) = \#(x)\#(y)$.

To illustrate the upper limits in (2.4) and (2.5), we will choose the situation

$$\#(x) = 100, \quad \#(y) = 20,$$

while to illustrate the lower limits we choose

$$\#(x) = 50, \quad \#(y) = 20 ;$$

then (3.9) yields about 23 minutes where (3.6) gave 45 minutes, and yields about $4\frac{1}{2}$ minutes where (3.6) gave 9 minutes. In general, (3.9) is about half of (3.6). For a rectangular array, (3.9) becomes

$$\#(t) \left[.0089 + \#(x) \left\{ 1 + \#(y) \right\} \right]. \tag{3.13}$$

If we have a rectangular array, we can push the above idea still another step, by computing

$$e^{bx/u} \quad \text{and} \quad \exp\left\{ \frac{-(x-ut)^2}{k(t^{\beta}+\alpha)} \right\}$$

for each x-value, and

$$\exp\left\{ -y^2/k(t^{\beta}+\alpha) \right\}$$

for each y-value, reducing (3.13) to the estimate

$$\#(t) \left[.0089 + .0052\#(x) + .0026\#(y) \right], \tag{3.14}$$

which yields about $2\frac{1}{2}$ minutes where (3.9) gave 23 minutes, and about 45 seconds where (3.9) gave $4\frac{1}{2}$ minutes.

In passing from step to step in the above analysis, the number of "fast operations" which we have been ignoring (e.g., multiplications and divisions) has steadily risen, which somewhat offsets the reductions in computation time discussed above. Nevertheless, the analysis makes it clear that the correct approach is to assume a rectangular array and arrange the computations as described in the last paragraph; non-rectangular arrays could be handled by

inserting commands to delete some points of a "circumscribed" rectangular array.

The special case a = 0 (instantaneous source) is of interest, since then e^{-bt} and $e^{bx/u}$ need not be calculated, so that (3.14) is reduced to

(3.15) $$\#(t)\ [.0063 + .0026\{\#(x)+\#(y)\}] ,$$

which yields about 1½ minutes where (3.14) gave 2½ minutes, and about 20 seconds where (3.14) gave 45 seconds. Thus it seems worthwhile to have the computer program make a special check on whether a = 0. On the other hand, the special case of a point source ($\alpha = \alpha_z = 0$) need not be checked, since it offers practically no saving in computation time.

The material developed so far is outlined in Figure 2. Discussion of BLOCK 1A (Prepare Constants) and BLOCK 1B (Print Out Table t) is postponed to the next section.

4. Discussion of BLOCKS 1A and 1B.

The "constants" alluded to in BLOCK 1A are the quantities Q_o, a, b, α, α_z, k, k_z, β and u, which were regarded as "given" in Section 5. The simplest situation with respect to these quantities occurs if

(i) the quantities have the same values for all the munitions of each particular simulation[9], and

(ii) the quantities do not change from simulation to simulation within a sample.

If both (i) and (ii) hold, then the values of Q_o, ..., u are given at the beginning of calculations for the sample, and BLOCK 1A simply involves looking them up.

It may be desired, however, to "randomize" one or more of these quantities, in which case BLOCK 1A would involve selecting values of each of the randomized quantities from the appropriate random distributions, and looking up the values of the remaining (non-random) ones. Rough estimates of the computation time required to select a single random number from each of the indicated distributions are:

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(9) That is, each simulation involves a set of munitions which all have the same characteristics.

Distribution	Time (in sec.)
Rectangular	.0001
Normal	.0014
Exponential	.0023

In order to explore the effect of such randomization on computation time, we define

(4.1) $\#(s)$ = number of simulations/sample,

(4.2) $\#(m)$ = number of munitions/simulation.

If condition (ii) is violated, then it is necessary to go through BLOCK 1 for each simulation, instead of just once for the entire sample, so that the computation time (for the sample) spent on BLOCK 1 is effectively multiplied[10] by $\#(s)$. Since $\#(s)$ must be rather large in order to obtain a statistically valid sample, and since BLOCK 1 contains the heaviest part of the calculations, the resulting increase in computation time per sample would limit[11] the number of samples (i.e., the number of different cases) considered; this may prove too heavy a price for the additional element of randomness introduced. We cannot estimate $\#(s)$ in advance; preliminary experience with the program should give some idea of

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(10) Each passage through BLOCK 1 is also lengthened by the task of choosing random numbers.

(11) Assuming reasonable limitations on the funds available for the computation.

the size of #(s), and may perhaps suggest how #(s) can be reduced by use of appropriate "statistical designs."

The situation is analogous if condition (i) is violated. Here the time spent on each passage through BLOCK 1A is multiplied by #(m), and the number of values of $\chi(x,y;t)$ to be calculated is multiplied by #(m); this not only increases computation time, but also multiplies by #(m) the "output time" from BLOCK 1 and the corresponding "input time" to BLOCK 4.

From the considerations of the last two paragraphs, we are led to recommend strongly that only samples obeying (i) and (ii) be taken. The machine time thus saved can be used to much greater advantage in increasing the number of samples (i.e., the number of cases) considered, thus permitting a systematic (rather than randomized) study of the effects of varying the meteorological factors and munitions parameters. Throughout the rest of the report, we assume this recommendation is followed.

Turning to BLOCK 1B, we remark that the output from BLOCK 1 will consist of a number of tables, each corresponding to a particular t-moment. A single such table, Table t, consists of the values of $\chi(x,y;t)$ for all (x,y)-points. If we make the very rough estimates

(4.3) 120,000 data on a magnetic tape,

(4.4) 60 seconds to write out or read in a tape

then, assuming the upper limits in (2.4) and (2.5), we would have about 4 tapes, each containing 60 tables with 2000 entries each. The output from each run through BLOCK 1 would thus require about 4 minutes to write out, and about 4 more minutes to read in when BLOCK 4 is reached. This adds emphasis to the recommendation made above.

5. Selection of Intake Functions (BLOCK 2)

In this section we describe, in general terms, how the program generates an intake function (whose independent variable is time t) for the person (if any) at each (x,y)-point of the region. It will be convenient to change our notation slightly (by capitalization) and speak instead of "(X,Y)-points" and of "T-moments". The intake function will be denoted

(5.1) I(X,Y;T) = intake rate at time T of person at (X,Y).

We shall suppose that the personnel in the region can be classified by activity level, and that the number of activity levels is small (at most 5, say); that is, we group the personnel very roughly according to the degree of physical exertion connected with their duties. For example, "sleeping" and "marching" might be appropriate activity levels; formally, "absent" might be included to signify that there is no person at (X,Y). The program is to select, in whatever deterministic or random way is prescribed,

(5.2) A(X,Y) = activity level of person at (X,Y)

for all (X,Y)-points.

Second we assume given, for each activity A, a function[12]

(12) This should prove a satisfactory alternative to a single function I(T;θ) involving a set θ of random parameters.

(5.3) $I(T;A)$ = pre-masking intake for activity level A.[13]

Third, we define

(5.4) $\mu(X,Y)$ = masking time for the person at (X,Y);

the values of $\mu(X,Y)$ are chosen from a prescribed random distribution. The intake function is then in effect defined by

$$(5.5) \qquad I(X,Y;T) = \begin{cases} I(T;A(X,Y)) & \text{for } T \leq \mu(X,Y) \\ 0 & \text{for } T > \mu(X,Y) \ ; \end{cases}$$

if desired, the second line of the definition can be altered to involve a leakage term.

The output of BLOCK 2 consists of a table of $A(X,Y)$ and a table of $\mu(X,Y)$. These tables can probably be kept in the computer. The arrangement of the work is shown in Figure 3.

(13) The functions proposed in the Project Caramu reports have the property that any particular functional value can be rapidly computed; we assume (for the purposes of BLOCK 4) that each $I(T;A)$ has this property. $I(T;A) = 0$ for A = "absent".

6. Generation of Munition Arrivals (BLOCK 3)

We use the notation

(6.1) (ξ_i, η_i) = point of arrival of the i-th munition,

(6.2) τ_i = time of arrival of the i-th munition.

These points and times of arrival are selected from prescribed random distributions; a detailed discussion seems unnecessary. We note, however, that (ξ_i, η_i) must be an (x,y)-point and τ_i must be a t-moment, so that we are actually dealing with discrete distributions which approximate the (presumably) continuous prescribed distributions. The approximation can be made by choosing random values according to the continuous distribution, and then "rounding off" to the nearest (x,y)-point and t-moment.

7. Computation of Total Doses (BLOCK 4)

In this section we describe the calculation, for all (X,Y)-points, of the quantity

(7.1) $D(X,Y)$ = total dose received by person at (X,Y).

In terms of (5.1), (5.2), (5.3) and (7.1), we have

$$(7.2) \qquad D(X,Y) = \int I(X,Y;T) \sum_i \chi(X-\xi_i, Y-\eta_i; T-\tau_i)\, dT,$$

where the summation is over all munitions. The integral is not available in closed form, and so will be replaced by a finite sum

$$(7.3) \qquad D(X,Y) = \left(\sum_T c_T\, I(X,Y;T) \sum_i \chi(X-\xi_i, Y-\eta_i; T-\tau_i)\right) \Delta T$$

where "$\sum_T$" is a sum over all T-moments, and

(7.4) ΔT = difference between consecutive T-moments.

The constants c_T are the "weighting factors" of the numerical integration formula employed; the trapezoid rule, in which

first c_T = last c_T = 1/2

all other c_T = 1,

will probably be adequate.

To bring (7.3) into a more convenient form, we first interchange the order of summation, obtaining

$$(7.5) \qquad D(X,Y) = \left(\sum_i \sum_T c_T\, I(X,Y;T)\chi(X-\xi_i, Y-\eta_i; T-\tau_i)\right) \Delta T,$$

and then replace the "dummy index of summation", T, in the i-th summand of "$\sum_i$", by the new "dummy index" $t = T-\tau_i$. In view of (3.4), the result (after again interchanging the

order of summation) is

$$(7.6)\quad D(X,Y) = \left(\sum_t \left(\sum_i c_{t+\tau_i}\chi(X-\xi_i, Y-\eta_i; t)I(X,Y;t+\tau_i)\right)\right)\Delta t.$$

The point of these maneuvers is that each summand in "$\sum_t$" involves just one value of t, and thus just one of the tables in the output of BLOCK 1.

During the calculations of BLOCK 4, a "cell" in the computer is set aside for each (X,Y)-point. Let

(7.7) N(X,Y) = the number stored in the cell corresponding to (X,Y) ;

as the computation proceeds N(X,Y) increases from 0 to $D(X,Y)/\Delta t$. The arrangement of the work is shown in Figure 4.

8. Counting Casualties (BLOCK 5)

A casualty assessment rule C is determined by a function

(8.1) C(D) = probability of casualty of a person has received total dose D.

There is no particular inconvenience in assessing casualties simultaneously for a number of such rules, given by respective functions.

(8.2) $C_1(D)$, $C_2(D)$, ..., $C_n(D)$.

A cell is set aside in the computer for each assessment rule. We designate

(8.3) N(k) = the number in the cell corresponding to the k-th assessment rule;

during the calculations of BLOCK 5 N(k) increases from 0 to the computed number of casualties using the k-th rule. The arrangement of the work is shown in Figure 5, in which r(X,Y) denotes a random number chosen from the uniform distribution on $0 \leq r \leq 1$.

Figure 1 : Skeleton Block Diagram

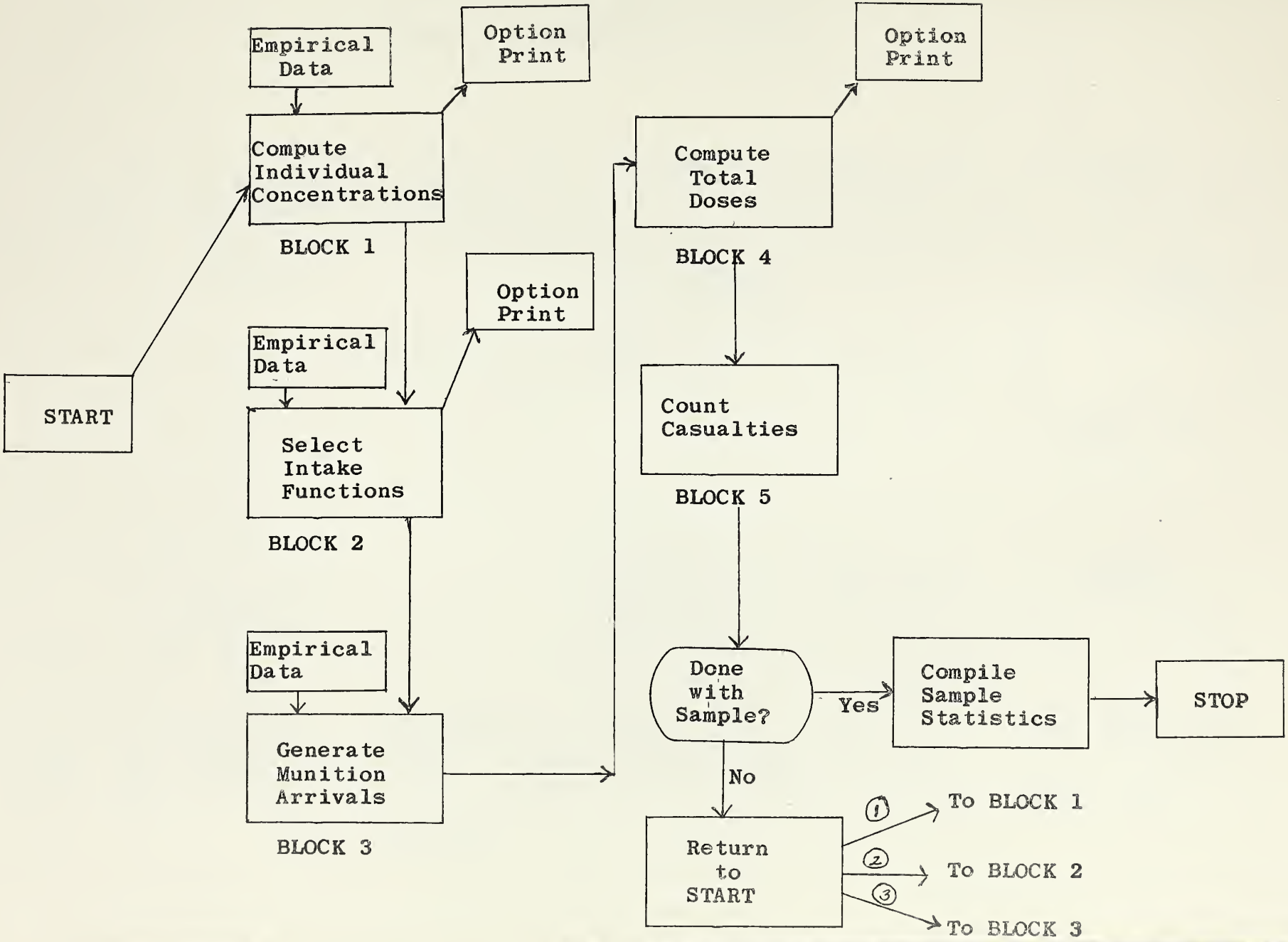


Figure 2 : Breakdown of BLOCK 1

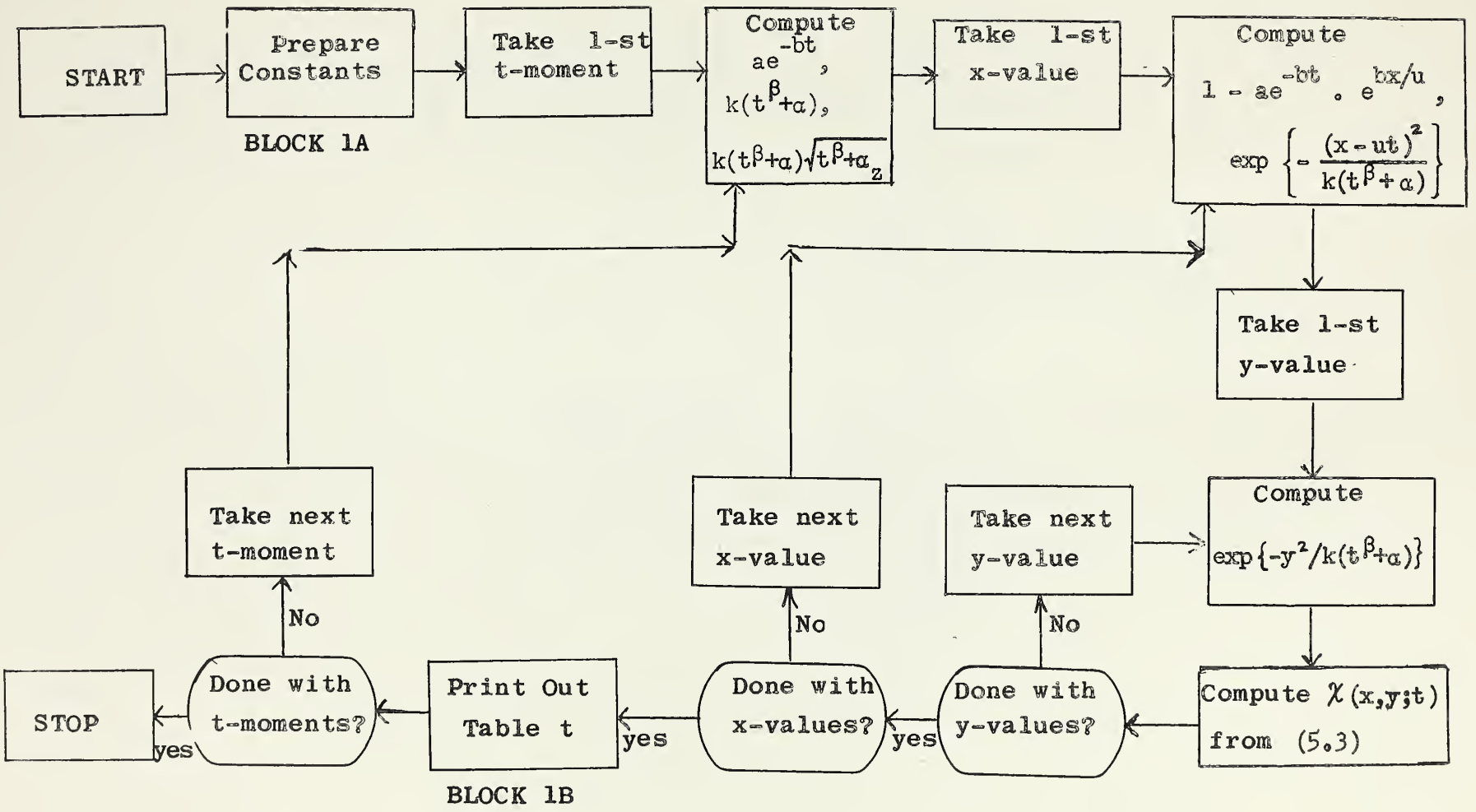


Figure 3 : Breakdown of BLOCK 2

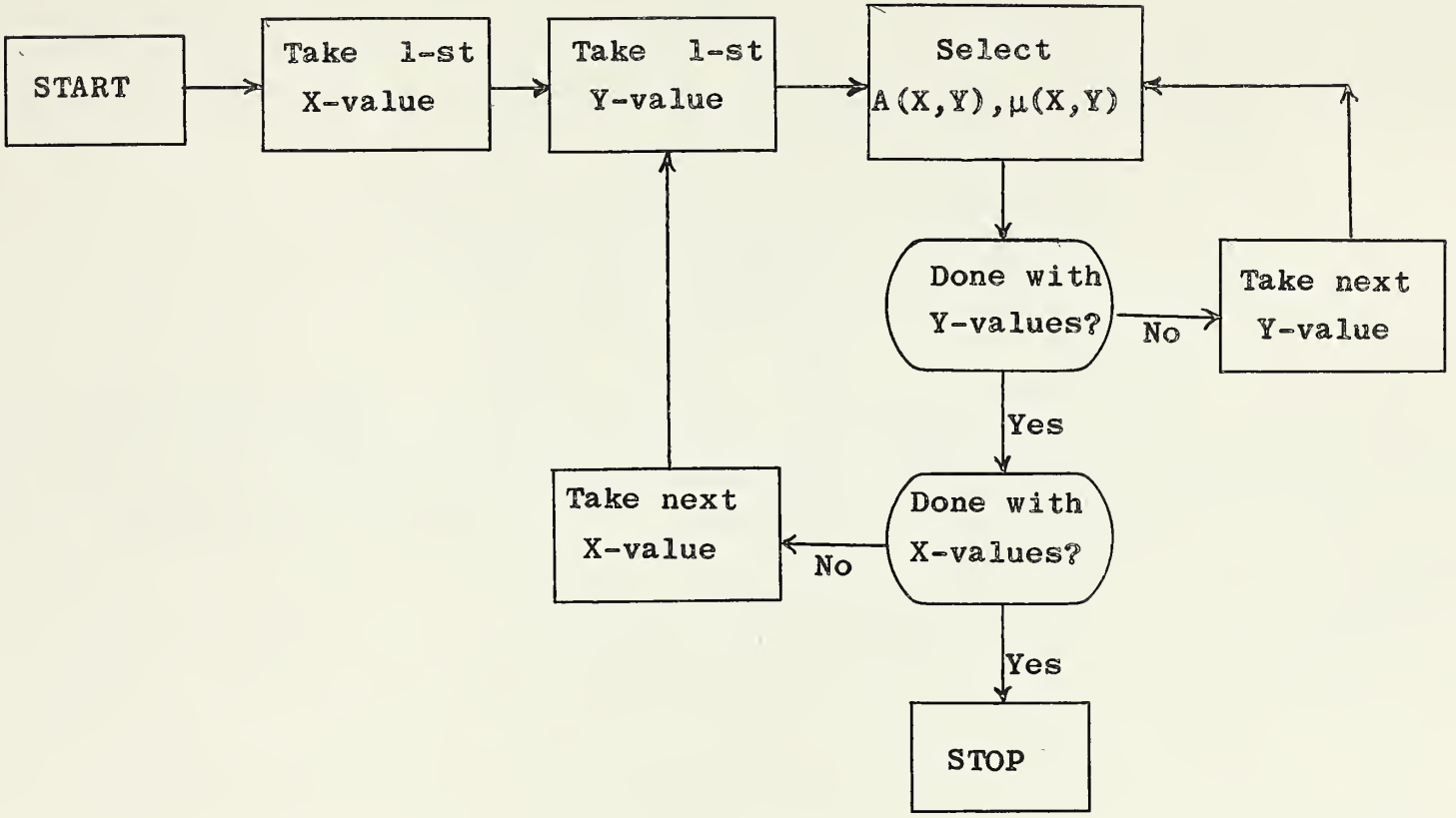


Figure 4 : Breakdown of BLOCK 4

Abbreviations: #(m) = number of munitions ; $S_i(X,Y;t) = c_{t+\tau_i}\chi(X-\xi_i, Y-\eta_i;t)I(t+\tau_i;A(X,Y))$.

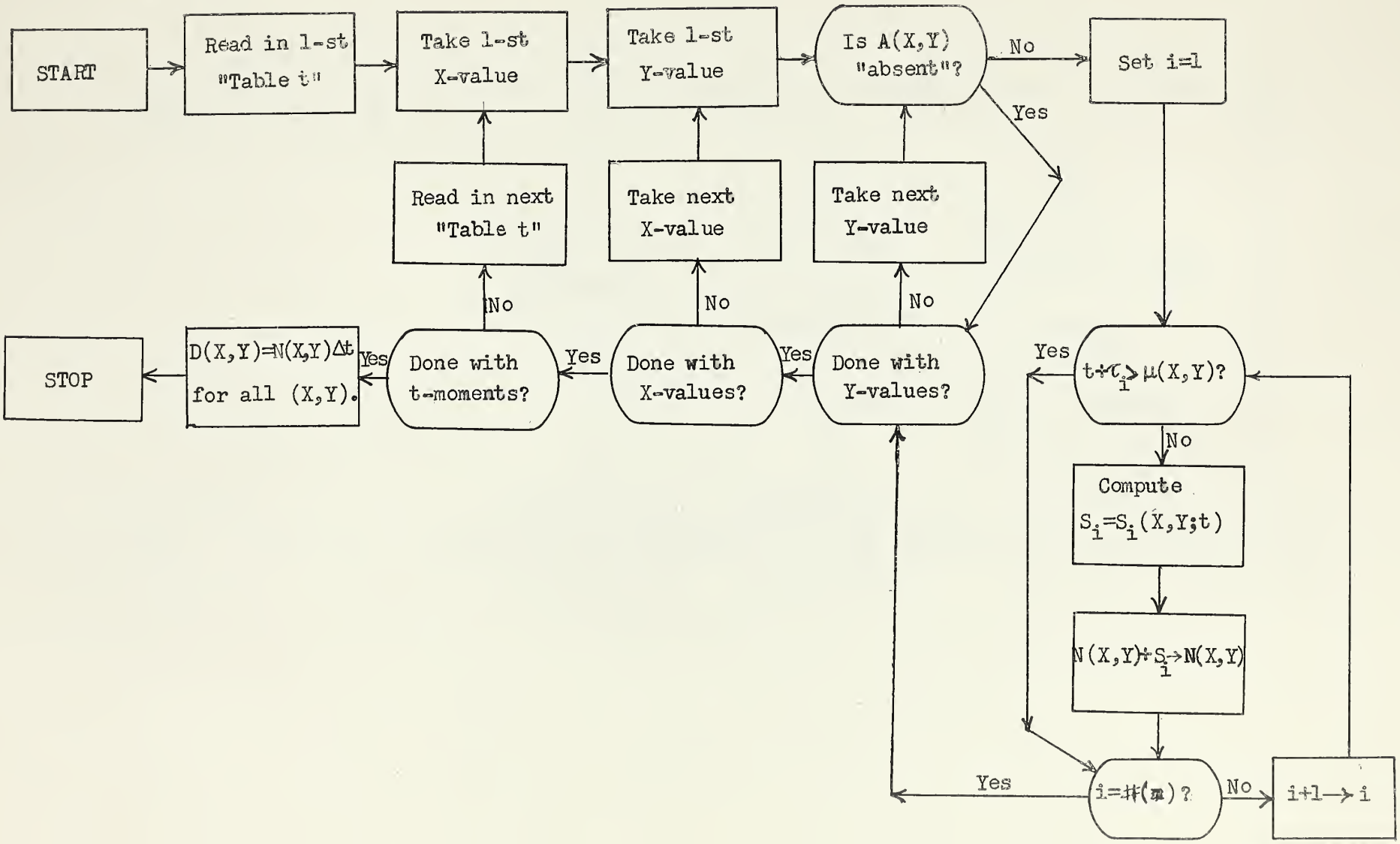
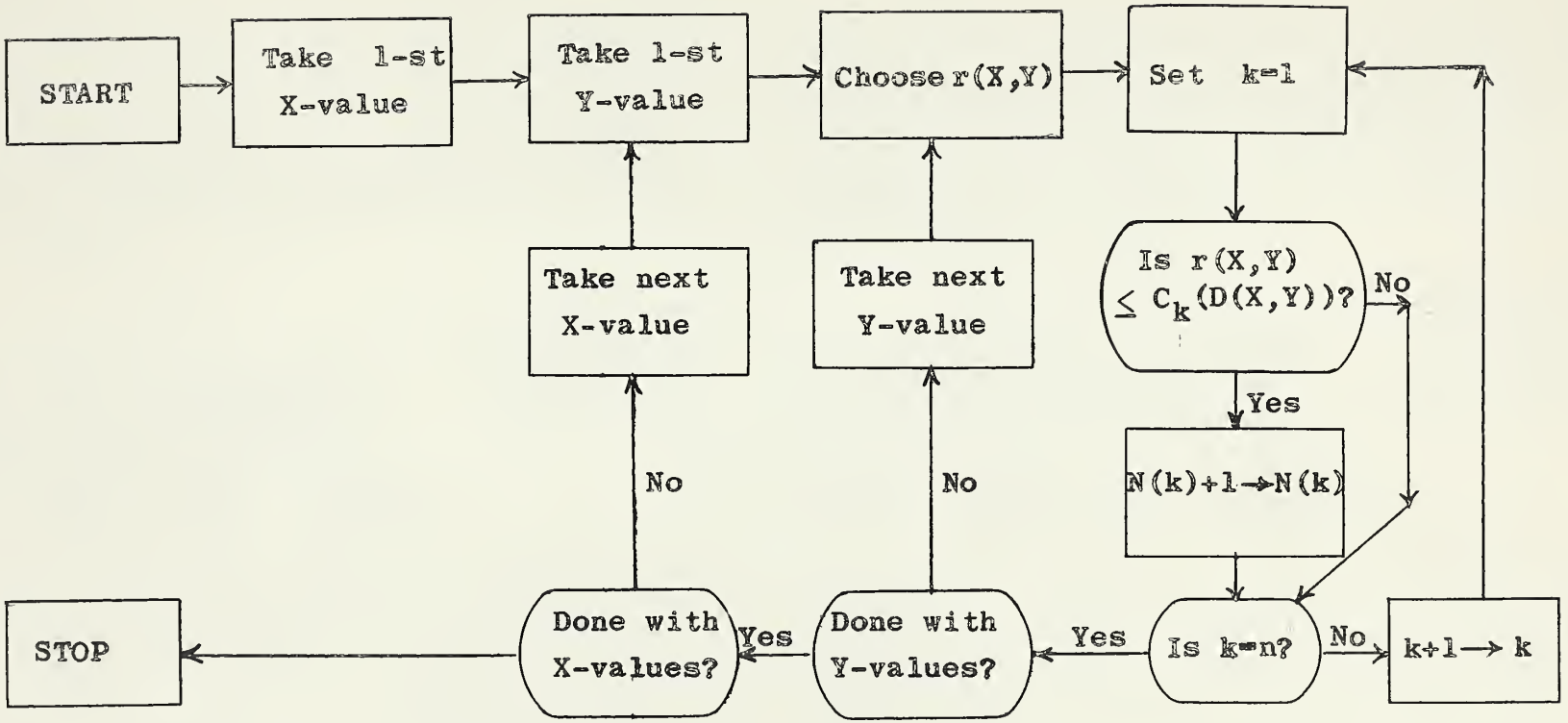


Figure 5 : Breakdown of BLOCK 5



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Lewis L. Strauss, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

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Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio-Meteorology.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.


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